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Automated pure-tone threshold estimations from extrapolated distortion product otoacoustic emission (DPOAE) input/output functions (L)[a]

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A promising approach to the prediction of pure-tone thresholds through the estimation of DPOAE thresholds by input/output functions was recently published by Boege and Janssen [J. Acoust. Soc. Am. **111**, 1810–1818 (2002)]. On the basis of their results, a device that enables automated measurements of these thresholds was recently developed. The purpose of the current study was to evaluate the reliability of this instrument for the objective assessment of hearing loss in 101 ears with either normal hearing or with cochlear hearing loss of up to 50 dB HL. The median difference between pure-tone hearing and DPOAE thresholds was approximately 2 dB. For individual subjects, however, DPOAE thresholds differed from pure-tone thresholds by up to 40 dB. We find, therefore, that the clinical benefits of this method are probably limited. © *2006 Acoustical Society of America.* [DOI: 10.1121/1.2180531]

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I. INTRODUCTION

Measurements of DPOAEs have been used to make dichotomous decisions, in which an ear is classified as having either normal to nearly normal hearing or as showing evidence of hearing loss. Several studies have attempted to move beyond this two-state classification scheme and actually attempted to predict pure-tone thresholds from DPOAE measurements (Gorga *et al.*, 1996; Martin *et al.*, 1990). One of the most promising approaches in this regard was recently developed by Janssen and co-workers using DPOAE-threshold estimation by extrapolating DPOAE input/output (I/O) functions with sophisticated parameter settings (Boege and Janssen, 2002). In their study, Boege and Janssen found that the majority of measurements showed a good relationship between DPOAE and pure-tone hearing thresholds in both ears with normal hearing and with mild to moderate cochlear hearing loss. The authors concluded that DPOAE measurements represent a reliable estimation of cochlear hearing thresholds up to a moderate cochlear hearing loss of 50 dB HL. However, for a significant minority of their measurements, pure-tone thresholds were poorly predicted by DPOAE input/output functions.

On the basis of the findings of Boege and Janssen, a device for measuring automated pure-tone threshold estimation by means of such DPOAE I/O functions, the Cochlea-scan, was recently developed by Fischer-Zoth, Germany. According to the manufacturer, this fast, easy to handle, and portable instrument provides "extended hearing screening" with both frequency-specific and quantitative information on hearing loss. It has also been proclaimed to be suitable for the fast evaluation of hearing function in any age group and monitoring of noise-exposed subjects. The aim of our present report was to evaluate the suitability of this device as a clinical tool for the objective assessment of hearing loss.

II. METHODS

A. Subjects

Subjects were classified into two groups. The first of these included 101 ears from 53 subjects (43 males; mean age 34 years, range 21–69 years) with either normal hearing or mild to moderate cochlear hearing loss (pure tone thresholds $\leqslant$50 dB HL from 1.5 to 4 kHz). Forty-two of these subjects were nonprofessional pop/rock band members (i.e., the main income of each subject had to be earned from "nonmusical" activities) who had been active in music for more than 5 years and had weekly exposures to intense sound levels by electro-amplification for at least 2 h. Our exclusion criteria were determined using the *Questionnaire for Hearing Tests* (ISO/TC43/WG1, 1996): (a) the occurrence of acoustic trauma, (b) excessive noise exposure during occupational activities, (c) a history of recurrent otitis media, (d) ear surgery, (e) fractures of the cranium, (f) ingestion of potentially ototoxic drugs, and (g) reported hearing difficulties in other family members.

The second group (control group) included 10 ears from 5 subjects (4 males; mean age 32 years, range 1–57 years) with documented profound hearing loss or deafness.

B. Pure-tone threshold measurements

Pure-tone air conduction thresholds at all standard frequencies from 0.25 to 8 kHz, including interoctave frequencies of 1.5, 3, and 6 kHz, were measured with a digital,

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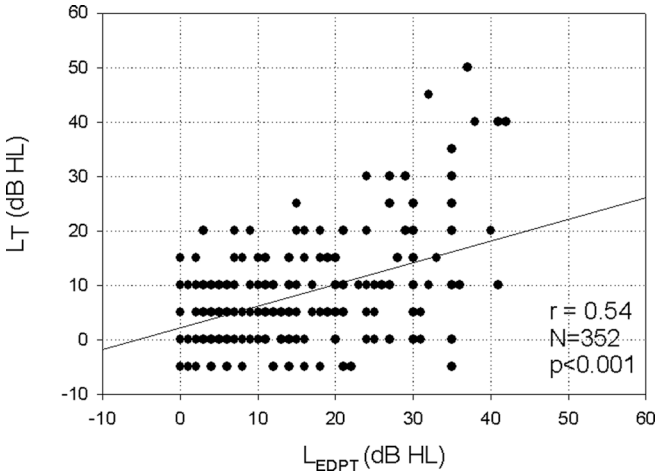

FIG. 1. Pure-tone thresholds (L_T) plotted against the estimated DPOAE thresholds (L_{EDPT}) for all frequencies.

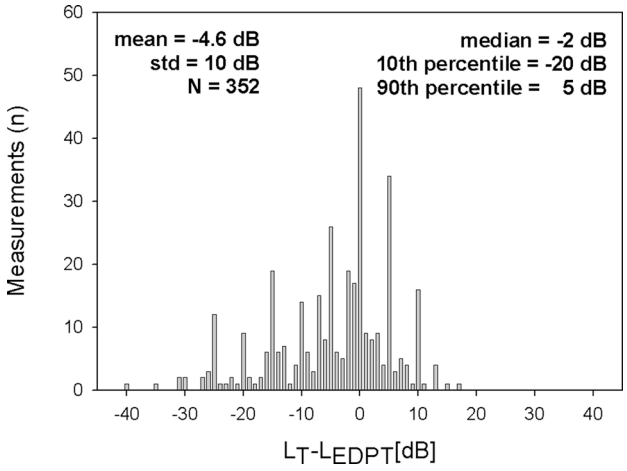

FIG. 2. Differences between pure-tone thresholds and estimated DPOAE thresholds ($L_T - L_{EDPT}$) for all frequencies.

PC-controlled audiometer (Insider of Audiocare, Switzerland) equipped with circumaural Sennheiser HDA 200 earphones. These measurements were obtained using a modified Hughson-Westlake procedure and were performed in a sound-treated booth, in which the ambient noise level was less than that recommended by ISO 8253-1 (1989). Conductive hearing loss was excluded by screening immittance measurements and otoscopy. The audiometer and earphones were calibrated according to the manufacturer's instructions.

C. DPOAE measurements

Automated pure-tone threshold estimations, by means of DPOAE I/O functions, were performed using the Cochlea-scan device under study according to the manufacturer's instructions. DPOAE I/O functions were measured at 1.5, 2, 3, 4, and 5 kHz for f_2. Primary stimulus levels for L_2 were 65 dB SPL and were reduced in 5-dB steps down to 15 dB SPL. The primary tone level for L_1 was $0.4^{*}L_2+39$ dB (Boege and Janssen, 2002). The estimated thresholds were displayed by the Cochlea-scan device.

D. Data analysis

Estimated thresholds from extrapolated DPOAE I/O functions were compared with the corresponding "behavioral" pure-tone thresholds for single standard frequencies at 1.5, 2, 3, and 4 kHz. Pure-tone thresholds at 5 kHz were not measured in this study because we used a commercially available audiometer with standard parameter settings.

III. RESULTS

A. Ears with normal hearing or mild cochlear hearing loss

From the 101 ears with normal hearing or mild cochlear hearing loss, a total of 402 DPOAE I/O-function measurements were performed. Three hundred fifty-two of these (88%) could be processed by the Cochlea-scan system for the estimation of pure-tone thresholds. Figure 1 shows the pure-tone thresholds (L_T) plotted against the estimated DPOAE thresholds (L_{EDPT}) for all frequencies in the 101 ears. A moderate but significant relationship between the DPOAE thresholds and pure-tone thresholds is demonstrated by this linear regression, with a calculated slope of almost 0.5 and a correlation coefficient (r) equal to 0.54. A good relationship was also shown for measurements with pure-tone thresholds $\geqslant$30 dB HL in comparison to the estimated DPOAE thresholds, whereas the relationships between measurements with pure-tone thresholds of $\leqslant$20 dB HL and the corresponding estimated DPOAE thresholds were clearly poorer. For example, the estimated DPOAE thresholds ranged from 0 to 42 dB HL for a given pure-tone threshold of 10 dB HL. The distribution of the differences between the pure-tone thresholds and estimated DPOAE thresholds are shown in Fig. 2. The median difference was −2 dB, the range between 10th and 90th percentile 25 dB. To allow comparison with the results in the literature, the mean value and standard deviation are also indicated in spite of a sleeved distribution of these differences. The distribution of the differences between the pure-tone and the estimated DPOAE thresholds is shown in Table I for the tested frequencies. The mean values and standard deviation were the lowest at 4 kHz in comparison to lower frequencies, consistent with previous reports (Gorga *et al.*, 2003).

Threshold estimations by means of DPOAE I/O functions could not be accomplished for approximately 12% of the tests. The mean measuring time for one ear was found to be 760 s (s.d. 214, range 137–999).

TABLE I. Differences at single frequencies between the pure-tone thresholds and estimated DPOAE thresholds ($L_T - L_{EDPT}$) for 101 ears with either normal hearing or mild to moderate cochlear hearing loss.

	Frequency (kHz)				
	1.5	2	3	4	1.5–4
Median (dB)	−7.5	−5	−1	0	−2
Mean (dB)	−9.5	−5.2	−3.9	0.5	−4.6
SD (dB)	9.9	10.1	10.4	6.5	10
L_T (n)	100	101	100	101	402
L_{EDPT} (n)	92	92	84	84	352

B. Ears with deafness or profound hearing loss (control group)

DPOAE thresholds could not be determined for any of these ears ($n=10$) with severe hearing loss. The mean measuring time for each ear was 215 s (s.d. 98, range 114–420).

IV. DISCUSSION

Our results showed median differences of 2 dB between the pure-tone and DPOAE thresholds for ears with either normal hearing or moderate cochlear hearing loss, which is excellent for clinical use. A number of our findings, however, must be considered as limitations to the clinical use of the Cochlea-scan. First, threshold differences of up to 40 dB were detected in individual cases, as shown in Fig. 1, and our analysis demonstrated a 10-dB standard deviation for these calculations. These results were consistent with the results of Gorga *et al.* (2003). Second, pure-tone estimation by means of DPOAE I/O functions could not be accomplished in 50 of the 402 measurements (12%), which is consistent with previous reports (Boege and Janssen, 2002; Gorga *et al.*, 2003). Third, the measuring times for DPOAE I/O functions is significantly longer in comparison to the measuring times for routine DPOAE measurements (Meier *et al.*, 2004).

V. CONCLUSION

Prediction of pure-tone thresholds through estimation of DPOAE thresholds by input/output function using the Cochlea-scan device was excellent for group means, but poor for a significant portion of the individual subjects. This is consistent with the results of both Boege and Janssen (2002) and Gorga *et al.* (2003). The clinical benefit of threshold estimation by means of extrapolated DPOAE I/O functions is therefore probably limited.

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